Multiple Scattering and Volume-Roughness Interactions in Sea Bed Acoustics

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LONG-TERM GOALS

The goals of this research are to better understand bottom acoustic scattering at mid- and high-frequencies and to improve conventional algorithms for remote acoustic characterization of marine sediments.

OBJECTIVES

The primary scientific objective is to develop improved theoretical models for seabed scattering using approximations having a wider range of applicability than those presently available.

APPROACH

There are different scattering mechanisms due to different types of seabed medium irregularities: continuous volume fluctuations of the sediment acoustic parameters, discrete inclusions (rock, shell hash, etc), roughness of the seabed surface and internal interfaces, as well as volume-roughness interactions. In a rigorous and general form, they all can be considered in the frame of a unified approach [1] based on an integral equation for the field in the complex medium with arbitrary volume and roughness irregularities. A general full-field solution can be obtained with the help of well developed numerical approaches using finite element approximations to reduce the integral equation to a system of algebraic equations along with Monte-Carlo methods for statistical analysis. Although such numerical analysis is presently very time consuming for realistic medium parameters, it will be of practical in the near future. Its application could be validation of various analytical approximate methods incorporating multiple scattering effects.

One such approximate method, a Cumulative Forward-scatter Single Back-scattering (CFSB) approximation [de Wolf, 1971], appeared to be applicable for treating multiple scattering in sea bed sediments [2] and its modification was used in this work. The method makes it possible to relate the back-scattered intensity to the fourth moment of the field propagating in the sediment, a solution which can be obtained using various approximations, e.g., analytic PE, or numerically. The condition of validity for this method, unlike the small perturbation method, is smallness, not of the total scattered intensity integrated over all directions, but only for the backscatter direction, which for heterogeneity scales not small in comparison with the wavelength is a much weaker requirement.

WORK COMPLETED

The case of Gaussian statistics for the field fluctuations was considered. This assumption seems to be reasonable in the most interesting case of a strongly heterogeneous medium and makes it possible to express the fourth moments of the field propagating in the sediment through its first and second moments. For this case, an analytic expression for the multiple scattering intensity in a continuous inhomogeneous medium was obtained and analyzed. This permitted tests of the conditions of validity for conventional single scattering approximations. Also, some specific signatures of seabed properties in scattering were demonstrated. Various multiple scattering effects were analyzed and possible ways for their experimental testing were presented.

RESULTS

It was shown that conventional single scattering approximations can fail at realistic values of sediment parameters and examples were presented where multiple scattering effects should be taken into account. Unlike seawater or the atmosphere where fluctuations of sound speed are of primary importance, in marine sediments the density fluctuations were shown to be of critical importance. This arises because of the greater strength of non-forward scattering by strong fluctuations of the density, which is typical for marine sediments. However, the opposite case, where the relative fluctuations of sound speed are comparable to or bigger than fluctuations of density, is shown to be possible for marine sediments as well. This can result from, e.g., presence of micro gas bubbles in the sediment, which has a minor effect on density but significantly changes the compressibility and sound speed. In this case, it was shown that the field should be strongly fluctuating and randomized in a significant part of the insonified sediment volume to provide the level of the back-scattered intensity usually observed for the seabed. This means that the mean field in the sediment disappears at depths small with respect to the depth of penetration of the total field. Also, this result shows the error in some so-called self consistent theories of multiple scattering which consider only scattering of the mean field and neglect, first, scattering by density fluctuations and, second, contributions of scattering of the totally randomized field which in this case is dominant.

A fundamental effect of multiple scattering is the so called enhancement of back-scattering, which can double the intensity with respect to single scattering. However, for realistic sediment parameters, it is shown that this effect can be reached only when sound speed fluctuations are dominant. If such an enhancement is considered as unimportant from a practical point of view, considering the usual level of experimental errors and environmental uncertainties at sea, single scattering approximations can give reasonable estimates for the intensity of back-scattering beyond their rigorous conditions of applicability. However, this conclusion can fail when applied to near-forward directions because of the field randomization mentioned above. This means also that the effects of multiple scattering should be much stronger in stratified sediments, where the forward scattered field can be returned to the water due to refraction and reflection on internal interfaces.

Generally, multiple scattering effects are much more pronounced for near-forward directions in the sediment than for backscattering. For sediments, density and sound speed fluctuations are responsible for different directions of scattering. The density fluctuations play a dominating role for scattering in directions not close to forward and their contribution can be considered with acceptable accuracy in the frame of a single scattering approximation. The forward scattering is determined by fluctuations of sound speed even if they are small. This can cause strong multiple scattering effects for the propagating field and should be taken into account, in particular, in planning future experiments on seabed scattering in forward or near specular directions or propagation in or over the sediment, where the previously mentioned randomization of the field can be tested.

IMPACT/APPLICATION

The models of seabed scattering developed in this research [1-17] will provide a better understanding of bottom acoustic interaction at mid- and high-frequencies and can be incorporated in simulations used to predict sonar performance and as a basis for improved algorithms for remote acoustic inversions for seafloor properties.

TRANSITIONS

The results of this work are being adapted in practical models for seabed scattering. For example, a high-frequency bistatic scattering model funded by the ONR Torpedo Environments Program (6.2) incorporates the elastic scattering model developed as part of this work. The correlation method for identificating and/or separating the volume and roughness components of scattering is proposed for use during ASIAEX and other ONR experiments.

RELATED PROJECTS

This research is conducted jointly with the separately funded work of D.R. Jackson and comparisons with CBBL data have been carried out in collaboration with Kevin Briggs, Kevin Williams, Chris Jones and Tim Orsi. The approaches and models developed in this research are relevant to acoustic penetration and multiple scattering issues arising within the ONR Departmental Research Initiative on high-frequency sound interaction with the seafloor.

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